ADS-B Link Decision Workshop
Session B
User Application Assumptions

1. At a minimum, the selected link or link combination will support the following set of baseline applications:
   - OEP/AD-5: Expand Use of 3-Mile Separation Standard (related to SF21/8.2 & 8.3)
   - OEP/AD-6: Coordinate for Efficient Surface Movement (with AD-7, related to SF21/6.2 & 7.1)
   - OEP/AD-7: Enhance Surface Situational Awareness (with AD-6, related to SF21/6.2 & 7.1)
   - OEP/AW-2: Space Closer to Visual Standards (related to SF21/3.1.1, 3.1.2, 3.1.3, 3.2.1, 4.1.1, & 4.1.2)
   - OEP/ER-5: Reduce Offshore Separation

   - Related Applications:
     - SF21/3.1.1: Enhanced Visual Approaches - Visual acquisition with existing procedures, ADS-B only
     - SF21/3.1.2: Enhanced Visual Approaches - Visual acq. with new procedures using ADS-B only
     - SF21/3.1.3: Enhanced Visual Approaches - Visual acq. with new procedures using ADS-B & TIS-B
     - SF21/3.2.1: Approach Spacing for Visual Approaches
     - SF21/4.1.1: Enhanced Visual Acquisition of Other Traffic for See-and-Avoid (using ADS-B only)
     - SF21/4.1.2: Enhanced Visual Acq. of Other Traffic for See-and-Avoid (using ADS-B & TIS-B)
     - SF21/6.2: Airport Surface Situational Awareness
     - SF21/7.1: Enhance Existing Surface Surveillance with ADS-B
     - SF21/8.2: Radar-Like Services with ADS-B
     - SF21/8.3: Tower Situational Awareness with ADS-B

2. If additional candidate applications are also required in order to achieve significant user equipage, then the selected link or link combination will, at a minimum, also support these candidates. Candidate applications may include one or more of the following:
   - SF21/3.2.2: Approach Spacing for Instrument Approaches
   - SF21/3.4: Departure Spacing/Clearance (VMC in Radar)
   - SF21/4.2.1: Conflict Detection
   - SF21/4.2.2: Conflict Resolution
   - SF21/5.2.1: Pilot Situational Awareness Beyond Visual Range
   - SF21/6.1.1: Runway and Final Approach Occupancy Awareness (using ADS-B only)
   - SF21/6.1.2: Runway and Final Approach Occupancy Awareness (using ADS-B and TIS-B)
   - SF21/7.2: Surveillance Coverage at Airports without Existing Surface Surveillance
   - SF21/9.1: Radar Augmented with ADS-B in Terminal Airspace
   - SF21/9.2: Radar Augmented with ADS-B in En Route Airspace
   - SF21/1.1.1: Initial Flight Information Service - Broadcast (FIS-B)
   - SF21/1.1.2: Additional FIS-B Products
     (Although 1.1.1 and 1.1.2 are not ADS-B applications, they could potentially share the same link)

3. The earliest possible implementation for air-air applications starts in late 2001. The earliest possible national implementation for applications requiring ground infrastructure starts in 2006.

Excerpts from the OEP:

AD-5: Expand Use of 3-Mile Separation Standard

Expanded use of 3-mile separation standards and terminal separation procedures

Current separation standards allow for 3-mile separation when within 40-miles of a single radar sensor. By identifying opportunities to maximize the use of the 3-mile separation standard, additional airspace efficiency may be achieved. This would afford more efficient control of aircraft during transition to and from the airport.

.....Other methods of improving surveillance, such as improved radar update rates or other forms of advanced surveillance, may offer options to expand usage of 3-mile standards or reduce separation standards in transition airspace in the future. In particular, deriving equivalent position accuracy as that within 40 miles of a radar may be achievable through evolving technologies like ADS-B and/or improved surveillance processing.

AD-6: Coordinate for Efficient Surface Movement

Improved planning, movement, and decision-making due to shared situational awareness of surface operations

Tower controllers have limited information on the position of aircraft on the surface. Pilots have no electronic display of aircraft or ground vehicle position, velocity, or intent information. In addition, the ramp controllers, airport operators, and fixed-base operators have limited information on the location of aircraft on the surface. This lack of shared situational awareness results in inefficiencies in surface movement, gate management, and servicing of aircraft. Uncertainties in surface movement contribute to inefficient use of runways and have safety implications.

Distribution of position information on aircraft and selected ground vehicles can improve air traffic control, command and control, and services coordination on the surface. .....Shared situational awareness for personnel responsible for flight scheduling, servicing, piloting, ramp and ground control will be achieved through the same set of real-time position information on an airport surface display for all flights and other ground vehicles currently on the airport surface. The shared situational awareness will also benefit air traffic ground control. For example, at airports where a ramp area is not under air traffic control and is not fully visible from the Air Traffic Control Tower (ATCT), the real-time position of all aircraft taxiing to the ramp exit from their gate will be shown to the ground controller (so that the runway sequence of each flight can be considered the flight request for taxi clearance).

.....Airport surface safety will be improved through increased situational awareness resulting in safer operations on the airport surface.

.....The surface management system (SMS) provides tools to manage departure operations, including runway queuing and load balancing. The use of SMS in conjunction with other technologies will increase shared situational awareness of airport surface operations between the ATCT, the Ramp Tower, the TRACON facility, the Air Route Traffic Control Center (ARTCC) and the air carriers that operate at an airport, through the use of real-time position data and data link of key events. Several technologies will provide information that will improve shared situational awareness, including Automatic Dependent Surveillance - Broadcast (ADS-B) (w/multilateration), ASDE-3, ASDE-X, SMA, and DDTC. .....ADS-B will provide accurate down-link of GPS-based position reports for equipped aircraft and some vehicles. Multilateration will provide position reports for all aircraft and vehicles having tagged beacon transmitters. Traffic Information Service, Broadcast Mode (TIS-B) will provide equipped aircraft and ground vehicles fused position reports of all aircraft and vehicles, whether ADS-B equipped or not.

AD-7: Enhance Surface Situational Awareness

Improve surface navigation and traffic situational awareness with cockpit-based tools

The pilot uses visual navigation aids and controller communications to determine aircraft position on the runway surface and uses visual references to maintain separation from aircraft and other vehicles. While the controller is responsible for separation on the runway, the pilot is responsible for separation while taxiing to the runway or gate, regardless of airport visibility. Low visibility and reduced ability to see signage can lead to confusion in navigating the aircraft on the surface. This in turn can result in the reduction of safety and efficiency.

Cockpit-based tools provide more robust surface navigation increasing pilot awareness of the aircraft's position on the airport surface. These tools help the pilot guide aircraft along the surface in accordance with ATC instructions, or in accordance with a self-generated taxi plan in the case of non-towered airports. Initially, these tools will supplement the pilot's out-the-window visual assessment of the aircraft's position on the surface, its direction, and speed.

A cockpit moving map of the airport surface could use the same moving map/navigation display used in flight.

.....Other aircraft and surface vehicle traffic would also be displayed on the cockpit moving map for airports providing this added information via ADS-B/TIS-B. .....In normal operations, the pilot would use both the cockpit display and visual observation to develop the most complete traffic picture. In some cases, the display could be the only source of traffic information for the pilot. This might occur when another aircraft cannot be seen due to blind spots created by airport structures or by one's own wings or tail. Aside from its use for avoiding runway incursions and incidents, the pilot can also correlate traffic observed on the display with outside visual information, thereby easing the process of understanding the intended sequencing when several aircraft are being formed into a queue.

AW-2: Space Closer to Visual Standards

Using cockpit tools and displays to achieve VMC throughput capacity in all weather conditions

Most airports have established weather minima below which visual approaches cannot be conducted, primarily due to the difficulty for the pilot to visually acquire the runway or traffic in such weather. Currently, the requirement for visual approaches is ceiling 500 feet above minimum vectoring altitude and visibility 3 miles. However, other environmental conditions such as haze, sunlight, smoke, and patchy clouds may effectively prohibit visual approaches at higher ceiling and visibility values. Without a cockpit tool that provides situational awareness of the leading aircraft, it is difficult for the pilot to acquire and maintain visual acquisition of the leading aircraft in marginal VMC.

The primary objective .... is to help the pilot, through the use of the CDTI, visually acquire and identify an aircraft that has been referenced as traffic by ATC, so the controller may clear the aircraft for a visual approach. The CDTI will enable quicker identification since the pilot will be able to correlate the target aircraft and trajectory information from the CDTI to the actual traffic as seen out-the-window. With quicker identification of pertinent traffic, the need for additional traffic advisories or follow-on interactions between the pilot and controller should be reduced. Another objective is to better enable the pilot to obtain and maintain visual separation once it is initially established.

The primary advantage of this application is that the pilot of an ADS-B/CDTI aircraft will be better able to isolate the traffic to be acquired on the CDTI when the other aircraft is also ADS-B equipped. This advantage is made possible by features on the CDTI which display the call sign of other aircraft. This should permit even shorter visual acquisition times and greater pilot and controller confidence that the pilot has identified the correct aircraft. Consequently, this should result in lower pilot and controller workload and reduced communication burden. In addition, it is anticipated that this will result in the ability to continue visual approaches into marginal VMC. For example, as mentioned earlier, the ceiling requirement for visual approaches is 500 feet above minimum vectoring altitude and visibility 3 miles. With CDTI, the 500 feet criteria could be lowered. Also, since visual acquisition will be enhanced, visual conditions will be able to be maintained in marginal conditions for a longer period of time.

Additional operational applications will be explored for the use of "Along Track Separation" to maintain closer spacing during the approach phase to parallel runways separated by less than 2500 feet.

....Benefits for the enhanced visual acquisition/situational awareness are dependent upon the degree to which visual acquisition is extended into marginal VMC. This will vary from airport to airport.

ER-5: Reduce Offshore Separation

Provide communication, navigation, and surveillance services similar to domestic en route airspace

The NAS contains a significant amount of airspace that lacks surveillance coverage. Most notable is the portion contained in the Gulf of Mexico airspace, which is part of the ICAO Caribbean/South America region. An area of approximately 60,000 square miles in the Central Gulf of Mexico currently lacks all but the most basic CNS components. Separation assurance in these areas is provided through the use of non-radar procedures, which employ cumbersome and inefficient separation standards.

In the Gulf of Mexico, there are two major user communities: the high altitude users and the offshore users.

.....Gulf of Mexico operations will be changed to allow the use of domestic en route standards and procedures. These standards and procedures will be supported by the provision of surveillance and direct controller-pilot voice communication coverage across all required Gulf airspace. Appropriate CNS enhancements should be provided for the high altitude users (FL290 and above across the whole Gulf) and for the offshore users (above 1500 feet in the oil exploration and production areas).

.....The FAA is working with industry to determine if a combination of radar and ADS-B surveillance can be introduced in the Gulf. The introduction of surveillance into non-radar airspace will enable further reductions in aircraft separation.

.....These initiatives to enhance communication, navigation, and surveillance capabilities will allow for reduced separation standards, while providing parallel benefits to air traffic flow management and increasing airspace capacity and operational performance. The specific decision on enhanced CNS and other automation are interdependent, and must be treated and assessed as a whole with full awareness of operational and investment tradeoffs for alternatives.

.....Consensus must be reached that the benefits of Gulf CNS improvements outweigh related operator costs for equipage.

<u>Excerpts from the SF21 Conops</u>:

1.1.1: Initial Flight Information Service - Broadcast (FIS-B)

Today's flight environment demands that pilots and other operational personnel have ready access to accurate and up-to-date information on the current and forecast flight environment. The importance of this information to the safety and efficiency of flight operations cannot be overstated: "weather" is cited as a contributing factor in a significant portion of fatal and non-fatal aviation accidents. Although instances of poor pilot judgment will likely persist no matter what training and technology bring to bear, it is generally agreed that having (1) *improved access* to (2) *enhanced weather information* about one's current or proposed flight environment will lead to better assessments of risk - and ultimately safer decisions. In addition to safety considerations, the efficiency of flight operations can also be increased with improved access to weather information, and also timely information on the status of special use airspace (SUA) and NAS facilities.

The primary objective of this application is to provide the pilot with improved access to weather information and aeronautical data. For many aircraft operations, the only means of obtaining flight information is via VHF voice communication with a Flight Service Station or other service provider. The VHF voice link is problematic in two ways. First, there are many types of weather information that are not suitable for conveyance by voice, such as graphical weather products. In such a transfer, considerable detail and information is lost, often leading to a partial, or obscure, picture in the mind of the pilot. Second, voice radiotelephone channels often become congested in periods of active weather, leaving the pilot unable to obtain critical weather data. The goal, then, of this application is to provide the pilot (in flight) with a reliable, cost-effective means of obtaining FIS data in a pilot-friendly manner. The focus in this first FIS application is on improved access to standard text weather products (i.e., METARs, TAFs, SIGMETs, PIREPs, and NOTAMs), as well as a standard graphical product (i.e., NEXRAD weather radar depictions).

1.1.2: Additional FIS-B Products

In the same way that improved access to weather and other information can enhance flight operations (as described in the previous operational application, OA-1.1.1), producing and providing better weather products can enhance the pilot's ability to identify and manage risks in the flight environment. Over the past several years, significant research has been directed to improving meteorological sensors and modeling techniques, which may lead to more accurate and reliable characterizations of weather hazards such as icing and turbulence. When these products reach sufficient maturity, it will be necessary to provide them to the cockpit in order for them to accommodate full operational benefit. In addition to enhanced weather, operational information on the status of airspace, facilities, and Notices to Airmen (NOTAMs) can be used to gain operational efficiencies and address some regulatory concerns.

While the first application was focused on giving the pilot better access to elementary weather products via FIS-B, the primary objective of this application is to provide the pilot with access to enhanced weather and aeronautical data. Using the same basic FIS-B technology, it is now envisioned that the pilot will have better information on such hazards as icing, turbulence, lightning strike, and volcanic ash, as well as information on the status of special use airspace (SUA). In addition, information that may be of a regulatory nature (such as an FDC NOTAM) may also be included.

3.1.1: Enhanced Visual Approaches - Visual acquisition with existing procedures, ADS-B only

A visual approach clearance is an air traffic control (ATC) authorization for an aircraft on an IFR (instrument flight rule) flight plan to proceed visually to the airport. Prior to issuing a visual approach clearance, the controller must ascertain that the pilot has the airport and/or pertinent traffic in sight, and will issue advisories to help the pilot find the airport or traffic. When the pilot confirms that the required entity (airport/runway or traffic) is in sight, the controller can issue the visual approach clearance. Under such an authorization, the pilot assumes responsibility for navigation, terrain clearance, and separation from the referenced traffic. (The controller retains responsibility to resolve potential conflicts with other aircraft). Most airports have established weather minima below which visual approaches cannot be conducted - primarily due to the difficulty for the pilot to visually acquire the runway or traffic in such weather. However, other environmental conditions such as haze, sunlight, smoke, and patchy clouds may also effectively prohibit visual approaches at higher ceiling and visibility values.

The primary objective of this application is to help the pilot (through the use of the CDTI) to visually acquire and identify an aircraft that has been referenced as traffic by ATC, so that the controller may clear the aircraft for a visual approach. The CDTI should enable quicker identification since the pilot should be able to correlate the target aircraft and trajectory information from the CDTI to the actual traffic as seen out-the-window. With quicker identification of pertinent traffic, the need for additional traffic advisories or follow-on interactions between the pilot and controller should be reduced. Another objective is to better enable the pilot to maintain visual separation once it is initially established.

3.1.2: Enhanced Visual Approaches - Visual acq. with new procedures using ADS-B only

The background and objectives for this application build on those for 3.1.1. Under this application, the same basic concept of the visual approach clearance is applied. However, greater advantage is taken of the features of ADS-B/CDTI to permit the pilot to quickly acquire and confirm the relevant traffic. The objective is to streamline and quicken the process of issuing the traffic advisory, acquiring the traffic, and conducting the visual approach. This should result in reduced workload for pilot and controller.

3.1.3: Enhanced Visual Approaches - Visual acq. with new procedures using ADS-B & TIS-B

The basic background and objectives for this application is also the same as for 3.1.1 and 3.1.2: namely, to increase the ease and range of conditions in which visual approaches can be reliably conducted. Under this application, however, use is made of Traffic Information Service-Broadcast (TIS-B) to increase the number of aircraft that ADS-B/CDTI-equipped aircraft can "see". TIS-B effectively permits non-ADS-B (but transponder-equipped) aircraft to be displayed in ADS-B/CDTI cockpits. Although the TIS-B data will not be as accurate as complete ADS-B data, use of this system may provide an effective transition through the period when many aircraft are not ADS-B equipped.

3.2.1: Approach Spacing for Visual Approaches

Managing the spacing between sequential aircraft on arrival paths in the terminal area can be challenging for both pilots and controllers, and the consequences for operating on either side of "optimum" spacing are significant. If the following aircraft is too close to the one ahead, a go-around may be necessary. On the other hand, runway capacity is wasted when the gap between sequential aircraft is excessively large. Consistently achieving inter-arrival spacing that is closer to the optimum is an important step in reducing terminal area congestion.

There are many factors that determine the optimum spacing value, some of which are airport-specific. Runway exit geometry, for example, plays a major role in runway occupancy times - a key factor in runway capacity. In addition, practical limits are also placed on inter-arrival spacing due to wake turbulence concerns.

Regardless of what the optimum arrival spacing is, consistently working toward that optimum is problematic for both pilots and controllers. For the pilot on a visual approach clearance behind another aircraft, visually estimating the distance and closure rate on the preceding aircraft is difficult and imprecise, especially in demanding visual fields such as looking into the sun, or at night. In cases where the controller is solely managing inter-arrival spacing, several factors are present which also introduce imprecision. These include dissimilar speed profiles, inconsistent configuration and speed changes, communication delays, radar data accuracy, and the effects of wind gradients, to name only a few.

The primary goal in this application is to increase the precision and consistency of inter-arrival spacing of aircraft on visual approaches. The goal is *not* to define the optimum spacing, nor to explore the boundaries of minimum spacing: these are valid pursuits of other research efforts. Rather, the objective here is simply to exploit the potential of ADS-B and CDTI to allow the pilot to more precisely manage spacing on the aircraft ahead during a visual approach.

Another objective of this application will be to expand the use of ADS-B/CDTI in approach spacing maintenance to include not only long, straight-in final approaches, but also other terminal area routings leading to the final approach (for example, vectors to the final approach, or RNAV/FMS-based terminal area transitions).

3.2.2: Approach Spacing for Instrument Approaches

As mentioned in 3.2.1, lack of precision and consistency in arrival spacing contributes to go-arounds and wasted runway capacity. These problems exist in both visual and instrument approach conditions.

As in 3.2.1, the primary goal in this application is to improve the precision and consistency of inter-arrival spacing through the pilot's use of ADS-B/CDTI. However, the concept is expanded in this application to include instrument meteorological conditions (IMC) in the context of an instrument approach procedure, where the "out-the-window" visual component is gone.

Another objective of this application is to enable the controller to assign the spacing interval to the pilot in order to achieve an air traffic management objective (such as to create a gap for a departure). It should be noted that reducing IFR separation minima is *not* a goal of this application - that is left for other research efforts to attempt if desired. The goal here is to work within the context of current separation minima to give the pilot/controller community another tool to manage arrival operations.

3.4: Departure Spacing/Clearance (VMC in Radar)

During departure operations, the tower controller issues takeoff clearances to successive departures after he/she first ascertains (or anticipates) that all applicable criteria are satisfied. When a takeoff clearance cannot be immediately issued, ATC will either instruct the aircraft to “hold short”, or to “taxi into position and hold” (in order to have the aircraft prepared for timely initiation of the takeoff a short time later). There are times in this situation, however, when the controller cannot promptly clear the successive departure due to the necessity to complete other tasks, or to answer other radio calls. For aircraft holding in position on the runway, the delay in issuing the pending takeoff clearance increases its exposure to risks from other aircraft or vehicles. The delay in issuing the takeoff clearance to the succeeding aircraft, whether holding short or on the runway, increases the spacing beyond the minimum required in FAA 7110.65, thereby reducing the airport's overall departure rate.. In situations where there is steady demand on the runway for departures, the takeoff delays can have a cumulative effect for subsequent aircraft in the takeoff queue.

The objective of this Departure Spacing/Clearance application is to explore (through focused research, simulations, human factors studies, and operational evaluations), if ADS-B technology and procedural modifications can increase safety and improve airport departure capacity and efficiency. This application could provide ATC with a new “tool” for improving the airport departure rate by reducing the separation variability between successive departures. It could also improve pilot situational awareness, resulting in an increase in the safety and efficiency of departure operations, and better runway utilization. An application such as this may be important, NAS-wide, for future terminal area concepts, such as variable wake turbulence separation between successive departing aircraft.

4.1.1: Enhanced Visual Acquisition of Other Traffic for See-and-Avoid (using ADS-B only)

The principle of "see-and-avoid" (whereby the pilot visually searches out the window for other aircraft, and alters flight path to avoid them if necessary) is well-established in regulation, procedure, and practice. FAR 91.113(b), for example, admonishes that "when weather conditions permit, regardless of whether an operation is conducted under instrument flight rules (IFR) or visual flight rules (VFR), vigilance shall be maintained by each person operating an aircraft so as to *see and avoid* other aircraft." Other regulations define the minimum visibility and cloud clearance needed to support VFR operations, as well as right-of-way rules to coordinate the passage of aircraft and resolve potential conflicts.

In spite of its importance and use, however, there are practical limitations to see-and-avoid's effectiveness. First, even under the best visual conditions (in terms of lighting, visibility, contrast, etc.), the pilot's visual search for other aircraft is truly like looking for a "needle in a haystack", and potential conflicts may go unnoticed by the pilot. This is compounded, of course, with less-than-ideal conditions introduced by such things as haze, night, looking into bright sunlight, "noisy" visual background, or obscuration by one's own wings, fuselage, or other aircraft parts. Another factor is higher traffic density (particularly around airports) that requires the pilot to visually acquire and avoid perhaps several aircraft in a high-workload environment.

While there is a range of ATC services that can assist the pilot in visually acquiring other traffic, there are practical limitations associated with these, too. First, verbal "traffic advisories" issued by ATC based on radar information often lack the precision to effectively help the pilot conduct a visual search, although it is certainly helpful to be made aware there is traffic out there. Second, issuance of traffic advisories could quickly lead to controller and communication overload in high traffic densities. As a result, issuance of traffic advisories may be suspended in high workload situations. Finally, much navigable airspace in the NAS is outside of ATC radar or communications coverage (or both), and this curtails the availability of traffic advisories especially at general aviation airports in outlying regions.

In brief, the see-and-avoid principle falters in practice because of the difficulty for the pilot to visually acquire other traffic in a consistent and reliable manner, and current methods to assist him/her in this task are also lacking.

The goal of this application is simply to improve the pilot's ability to visually acquire other traffic, both in the air and on the ground, so that he/she can more effectively apply the see-and-avoid principle. Because initial visual acquisition is the part of see-and-avoid most prone to failure, improving performance in this area should greatly enhance the pilot's general awareness of proximate traffic, and provide an opportunity for earlier assessment of the situation.

4.1.2: Enhanced Visual Acq. of Other Traffic for See-and-Avoid (using ADS-B & TIS-B)

The same background for the previous application (4.1.1) also applies here. It is generally accepted that having a CDTI in the cockpit greatly enhances the pilot's ability to visually acquire traffic that is observed on the display. This has been the airline industry's experience with TCAS. However, ADS-B/CDTI can aid in visual acquisition of only those aircraft it is capable of displaying to the pilot - unequipped aircraft will not show up on the display. As a result, its utility as a visual acquisition aid will be limited until most or all of the aircraft in the vicinity are equipped. This limited usefulness will be especially pronounced in the early period of transition to ADS-B as most aircraft will not be equipped.

The goal of this application is to effectively increase the proportion of aircraft which can be displayed as proximate traffic on an aircraft's ADS-B/CDTI, without regard to whether the proximate traffic is ADS-B-equipped or not. In so doing, the usefulness of the CDTI to the pilot is greatly increased as the same display device can be used to observe and aid in the visual acquisition of both ADS-B-equipped and non-equipped aircraft. This will be especially helpful in the early transition period when most aircraft will not be equipped.

4.2.1: Conflict Detection

Depending on the environment and the operating rules under which a flight is conducted, responsibility for ensuring safe separation from other aircraft could be distributed between the pilot and controller in three different ways:

(1) separation is the total responsibility of the pilot (for example, a visual environment in uncontrolled (Class G) airspace, or any airspace with only VFR traffic),

(2) separation is the total responsibility of the controller (for example, in Class A airspace, or in any controlled airspace under instrument meteorological conditions, in which case all aircraft must be on an IFR clearance), or

(3) separation is a co-responsibility of the pilot and controller (as in an environment where both IFR (ATC-controlled) and VFR (uncontrolled) coexist in the same airspace).

Regardless of who may have primary responsibility for separation (pilot, controller, or shared), the current techniques and tools to perform this function are sometimes subject to failure. In case (1) above (purely pilot-applied see-and-avoid), it is sometimes difficult to ascertain whether another aircraft presents a collision hazard, even after it is visually acquired. This is especially true when the target is distant and it is difficult to determine if it is flying toward or away from one's own aircraft. Other cases involve the other aircraft being involved in a turn, or closing at a high speed where there is not sufficient time to evaluate the situation.

In case (2) above, where the controller has primary responsibility for separation, breakdowns in communication, coordination, failure of the pilot to understand or adhere to a clearance, or controller error can cause safe separation to be compromised. Examples are plentiful, including stuck mikes, blocked transmissions, juxtaposed numbers, the wrong aircraft taking the clearance, and the "read-back/hear-back" phenomenon, to name a few. These problems are more prevalent under high pilot and controller workload situations.

In addition to the problems identified for (1) and (2), case (3) invites a unique set of risks associated with the "mixed" nature of the traffic. This is due to the fact that neither the controller or the pilot have a *complete* picture of what the other party is working with traffic-wise, and yet both are responsible for separation. As a result, this partial awareness hampers the effectiveness of both parties in ensuring separation.

A background to this application would not be complete without brief mention of TCAS. While the passenger-carrying airline industry has benefited from TCAS-II, this legacy system is technically limited. Because it is predicated on relatively sparse and poorly-behaved state data (Mode C or Mode S altitude data, range, and range rate, with no bearing data), extensive algorithmic processing is required - this drives the cost of the system up and yet the incidence of false alarms is still significant. In addition, the overall cost and complexity of the system puts it out of reach of operators who could most benefit from it.

The objective of this application is to enhance the basic awareness of proximate traffic that the pilot has gained through ADS-B/CDTI (see OA-4.1.1 and OA-4.1.2), to include a feature that alerts the pilot to traffic situations where safe separation may be compromised ("Safe separation" could be a fixed value, or it could be variable based on prevailing speed, airspace, phase of flight, or type of aircraft). This feature is intended to be useful in all phases of flight, and also to complement all three environments mentioned above. While it seems natural to wrap this capability with other features to produce a comprehensive "conflict management" package, there is also merit to developing and making full use of the component parts of such a package. Therefore, the goal here is to evaluate just conflict detection as a stand-alone complementary feature to current procedures. It is likely that, with the better data available via ADS-B, conflict detection will play a more significant, pre-emptive role - thereby reducing the need for more heroic conflict resolution functions. In addition, it is desirable that this feature be made available within reasonable cost so as to permit more users to equip.

4.2.2: Conflict Resolution

Conflict Resolution is one function under a broader concept called Airborne Conflict Management (ACM). The ACM concept includes detecting conflicts, monitoring for potential conflicts, and suggesting resolutions to prevent a violation of separation criteria from all other properly equipped aircraft/vehicles. ACM is envisioned as an important supplement to the provision of separation services by ground-based ATC, as well as an enabling technology for the implementation of the Free Flight concept.

The need for ACM, as a supplement to ground-based ATC separation, is apparent as one examines the various types of air traffic interactions in the NAS today. In current operations, for example, ensuring separation between IFR aircraft is the primary responsibility of the ATC system. While it is extremely reliable in this function, there are rare occasions when the required separation between two IFR aircraft is lost (e.g., due to communication breakdowns, hardware failures, or errors on the part of pilot or controller). In the absence of an airborne capability for conflict detection and conflict resolution, failure of this "single-thread" system puts the aircraft at risk.

The need for ACM is also apparent for operations conducted under VFR where "see-and-avoid" prevails as the primary separation method. As described in OA-4.1.1, environmental, physical, and other factors can hamper the effectiveness of the see-and-avoid technique for separation assurance. Currently almost all mid-air collisions are between general aviation aircraft in VFR conditions where a controller may not be involved. Operationally, ensuring separation under VMC in airspace that can accommodate both VFR and IFR aircraft is especially challenging. In this case, IFR aircraft will be ensured separation from other IFR aircraft by ATC. However, ensuring separation between two VFR aircraft or between a VFR and an IFR aircraft is left largely up to the pilots involved.

For these reasons, a first-generation airborne collision avoidance system (TCAS-II), which provides conflict detection and resolution, is required on passenger-carrying transport aircraft. However, this system is relatively expensive and somewhat constrained by its legacy-based design. Bearing information on another aircraft, for example, is poorly behaved and cannot be effectively used for conflict detection or avoidance. In addition, there is no provision to incorporate near term intent in the process of determining if a conflict exists, and if so, how it should be resolved.

The other motivation for ACM comes from the interest in flying user-preferred trajectories as envisioned in the Free Flight concept. A basic notion within this concept is that with more accurate data and longer-range intent information, conflicts can be anticipated and resolved earlier. This would permit use of minor changes to flight path, and provide a wider range of options for various encounter scenarios. However, TCAS-II cannot support this concept, and another system would be needed to provide information having the necessary attributes. Hence, there is a distinct need for an enhanced conflict resolution function to support the primary missions of the ACM system.

The objective of this application is to develop the final step in a complete airborne conflict management system, namely, conflict resolution. This system will be the basis for moving Free Flight forward while at the same time enabling major safety increases. A major focus of the application is to take advantage of the superior information made available in ADS-B position reports to enable advanced features that are not possible with TCAS-II. These include longer range, better miss distance calculations and filtering, more accurate bearing information to enable horizontal resolution maneuvers, and consideration of near-term intent of the aircraft involved. It is expected that use of ADS-B for ACM, including conflict detection and conflict resolution, will result in earlier and smoother maneuvers, vastly reduce the actual number of collision avoidance maneuvers required, and will make Free Flight and collision avoidance affordable for a larger segment of the user community.

5.2.1: Pilot Situational Awareness Beyond Visual Range

When considered in the context of the vast amount of navigable airspace and the high closure rates associated with modern flight operations, the range at which the VFR pilot can effectively see other aircraft is relatively short, even under ideal VMC. With more average conditions such as haze, for example, the effective range at which other aircraft can be seen is even shorter. As a result, in many cases maneuvers based on visual assessment and implemented for the purpose of avoiding a conflict with another aircraft are rather abrupt. This is simply a consequence of the short time available to visually acquire the traffic, assess the situation, and execute the maneuver. It has been often suggested that if the pilot could be made aware of the traffic situation at slightly longer ranges, he/she would be able to get a head start on the process and resolve potential conflicts with more modest maneuvers.

The main goal of this application is to provide pilots operating under VFR (or Special VFR) with an awareness of proximate traffic beyond visual range. The intent is to enable the VFR pilot to promptly anticipate and act on potential traffic conflicts, even before the other traffic is acquired visually. A secondary goal of this increased pilot awareness is in the pre-emptive role it can play. Awareness of relevant traffic beyond visual range can help the pilot select directions and altitudes that will yield fewer potential conflicts. It may also help him/her rule out some options for weather avoidance, for example, in favor of ones that present fewer potential traffic problems. It is also intended to be helpful to pilots transitioning between controlled and uncontrolled airspace, or transitioning between other airspace boundaries where an awareness of what is on the other side may be otherwise lacking.

6.1.1: Runway and Final Approach Occupancy Awareness (using ADS-B only)

From a historical perspective, almost all runway accidents occur because aircraft involved were unaware of each other. As the number of operations at the nation's airports increases with the rising demand for air travel, the industry's exposure to accidents on or near the runway surface also increases. In fact, the National Transportation Safety Board (NTSB) has listed "runway incursion" as the number two priority (out of the top ten) to improve civil aviation safety. It is expected that significant improvement in safety can be realized by increasing the pilot's awareness of other traffic in the vicinity of the runway - both in the air and on the ground.

The objective of this application is to increase the pilot's awareness of traffic (including aircraft and surface vehicles) that are on or near the runway surface, and also aircraft on final approach. This would be accomplished through the use of a CDTI displaying traffic information on other aircraft (or surface vehicles) suitably equipped with ADS-B. (6.1.2 covers a slight extension of this concept with the addition of TIS-B).

6.1.2: Runway and Final Approach Occupancy Awareness (using ADS-B and TIS-B)

The background for 6.1.1 also applies in its entirety to this application. However, while the previous application should greatly improve pilot situational awareness with respect to traffic on and near the runway, its effectiveness is limited in mixed-equipage environments where some aircraft and vehicles are not ADS-B-equipped.

As in 6.1.1, the primary objective of this application is to increase the pilot's awareness of traffic (including aircraft and surface vehicles) that are on or near the runway surface, and also aircraft on final approach. The objective is extended, however, so that the pilot is made aware of aircraft/vehicles that are not ADS-B-equipped, as well as those that are equipped. This will enable the pilot of an ADS-B/CDTI-equipped aircraft to have a more comprehensive picture of pertinent traffic on and near the runway.

6.2: Airport Surface Situational Awareness

Lack of pilot awareness of position on the airport surface (often coupled with not being aware of proximate aircraft or surface vehicle traffic), has been cited as a contributing factor in many ground collision accidents. The typical scenario involves a pilot who becomes disoriented or lost on the airport surface, usually due to being unfamiliar with the airport, or when visibility is impaired by such things as fog, snow, or even dark of night. The potential for disorientation is significant because, even in ideal visibility conditions, many airports have complex taxiway layouts with no distinguishing features to ascertain where one is on the airport surface. Some taxiway intersections are so complicated that signage intended to help the pilot sometimes adds more confusion. In any case, a disoriented pilot may occasionally stray onto a runway being used for takeoffs or landings, setting the stage for at least a runway incursion incident, or possibly an accident. Providing the pilot with a more reliable means of maintaining awareness of his/her own position on the airport surface, as well as that of other aircraft and surface vehicles, is an effective pre-emptive measure.

There are two basic goals of this application. One is to provide the pilot with cockpit-based tools to reliably increase his/her awareness of the aircraft's position on the airport surface. They would also assist the pilot in guiding the aircraft along the surface in accordance with ATC instructions, or in accordance with a self-generated taxi plan in the case of non-towered airports. At least initially, it is envisioned that these tools will supplement the pilot's out-the-window visual assessment of the aircraft's position on the surface, its direction, and speed. As the technologies and procedures mature, however, it is possible that the pilot could conduct all surface movements solely by reference to cockpit displays and systems - this would permit the much-sought-after capability of safely taxiing in "zero visibility" conditions.

The second goal is to provide the pilot with an awareness of proximate surface traffic (both aircraft and surface vehicles) on ramps, taxiways, and runways. While this would also reduce the threat of collisions on the surface, a secondary goal is to help the pilot better participate in the flow of traffic to or from the runway in accordance with ATC instructions.

7.1: Enhance Existing Surface Surveillance with ADS-B

Airport surface surveillance systems (such as Airport Surface Detection Equipment, ASDE) are being deployed at a number of the nation's busier airports that have large, complicated runway/taxiway configurations and high traffic volumes. The intent of these installations is to provide ground controllers with tools to enhance the safety and efficiency of surface operations. Because the ground controller's primary means of maintaining the traffic picture is by visual observation, the need for such tools is especially critical under conditions of reduced visibility or night where the controller cannot visually ascertain aircraft position and movement.

While ASDE does improve the ground controller's awareness of the surface operation under such conditions, it does have some practical constraints. First, ASDE is predicated on line-of-sight primary radar techniques that can be subject to shadowing from hangars or other airport structures. Also, the system sometimes has difficulty resolving two targets that are very close to one another, especially if one is large and the other is small. Finally, ASDE does not provide a data block showing target identity, and the resolution of the radar return does not normally permit quick detection of direction and speed of movement (though the controller can sometimes sense this by observing a target over time). These characteristics effectively limit the ways in which ASDE can feed surface movement automation.

This application explores the use of ADS-B to enhance existing surface surveillance systems to provide the ground controller with a more complete picture of the traffic situation. In particular, the goals of the application are to address the deficiencies identified above, and provide a level of redundancy for critical surface operations. It is intended that ADS-B will fill in gaps in ASDE coverage, as well as provide the controller with better information in the form of aircraft data blocks and better position/movement information.

7.2: Surveillance Coverage at Airports without Existing Surface Surveillance

While ASDE and ADS-B augmentation will provide safety and efficiency advantages to airports that are targeted for ASDE installation, the vast majority of airports, both towered and non-towered, will not be outfitted with ASDE. As a result, ground controllers at most towered airports will have no surveillance assistance to manage ground operations, except for direct visual observation. This means that operations conducted in reduced visibilities are at increased risk as there is no independent means to confirm that the pilot is correctly following taxi instructions. In addition, in conditions of reduced visibility the controller must build a mental picture of the ground traffic situation, based on taxi instructions he/she has given and pilot position reports – this contributes significantly to controller workload and frequency congestion.

The objective of this application is to provide the controller with a display of the ground traffic picture to enable him/her to monitor and manage the safe movement of aircraft and vehicles on the airport surface. While the previous application addressed the use of ADS-B at airports with ASDE, this application aims at providing a ground surveillance capability at towered airports without ASDE. As described for other applications of ADS-B on the airport surface, it is intended that information on surface vehicles would also be obtained using either the same ADS-B system, or one designed for and dedicated to surface vehicle traffic.

8.2: Radar-Like Services with ADS-B

While radar surveillance capability accounts for significant operational efficiency, safety, and improved services in the NAS, not all NAS airspace is under radar surveillance coverage. The effective coverage of ground-based radar systems is subject to line-of-sight and shadowing effects, and though radar coverage does exist down to near the surface in the vicinity of radar sites (such as in busier terminal areas), many outlying areas are without coverage. As a result, many flights operated at the lower altitudes or away from terminal areas will likely traverse non-radar airspace. The adverse impact this has on flight operations is best illustrated by considering the procedures and services that radar surveillance makes possible.

Where radar coverage does exist, for example, the air traffic controller can use a wide range of techniques to maintain IFR separation, such as aircraft vectoring and speed control. When coupled with the accuracy of radar-derived position data (as compared to pilot position reporting in a non-radar environment), these techniques allow much smaller separation minima to be applied, thereby increasing traffic throughput. In addition, radar surveillance capability makes it possible to offer a wide range of services to VFR and IFR aircraft, including flight following and traffic advisories, minimum safe altitude warning (MSAW), and navigational assistance, for example. Search-and-rescue activities can also be better focused if radar data are available for a flight presumed missing. All of these techniques and services require the accurate position information from radar to be operationally effective.

In spite of its importance in the provision of separation and other services, it is not cost-effective to site and install ground-based radar systems to achieve complete radar coverage of NAS airspace. As a result, operations in non-radar airspace are conducted using less-efficient separation techniques, and some services are not possible. IFR operations at many airports that are below radar coverage, for example, are subject to what is known as “one-in-one-out” procedures. Under such procedures, only one IFR aircraft at a time is allowed to enter the non-radar airspace, and no other aircraft can enter until the preceding aircraft either reports clear of the runway (in the case of a landing), or becomes radar-identified upon entering radar coverage after takeoff. As a result, aircraft awaiting takeoff or approach clearances while a preceding aircraft is completing an operation can encounter significant delays.

The objective of this application, simply stated, is to provide a cost-effective means to make the techniques and services associated with radar surveillance also available in non-radar airspace. This would include addressing those situations in non-radar airspace that pose the most significant constraints to IFR operations, such as “one-in-one-out" airports. An important aspect of the application is to ensure that controller and pilot workload is not adversely affected. While it is envisioned that radar services can be effectively replicated with new systems, it is not intended that these new systems be limited to mimic only what ground-based radar can support.

8.3: Tower Situational Awareness with ADS-B

At "VFR" towers (i.e., local control towers at airports not having a dedicated radar approach control facility), the local controller must rely on direct visual observation of the aircraft and/or pilot position reports to develop and maintain the traffic "picture" around the airport. While this is practical during periods of good visibility and with moderate traffic loads, it becomes more difficult for the controller as visibility conditions deteriorate due to such phenomena as local weather, bright sunlight on the horizon, or night conditions.

Aside from maintaining awareness of aircraft in the local traffic pattern, controllers at VFR towers must also make provision for inbound and outbound VFR and IFR aircraft. Often the initial call-up made by inbound VFR traffic occurs beyond the visual range of the tower controller. Likewise, coordination and hand-off of inbound IFR traffic also happens beyond visual range. Integrating such traffic into a landing sequence is more difficult for the controller until visual contact is established. Also, tower-center coordination for aircraft desiring a Special VFR (SVFR) clearance is more difficult.

The goal of this application is to provide the tower local controller at VFR towers with a tool to enhance his/her awareness of the traffic situation so that current local pattern procedures can be effectively applied. It is also intended through this application that the local controller will be better able to coordinate and plan for both inbound and outbound VFR, SVFR, and IFR aircraft.

9.1: Radar Augmented with ADS-B in Terminal Airspace

The resolution and accuracy of data from existing ground-based radar systems is sometimes a limiting factor in the development of automation aids and controller tools to increase airspace capacity. Radar separation minima, for example, vary as a function of range from the radar sensor to account for the greater influence of bearing error at more distant ranges. This reduces both the practical and theoretical capacity limits of a given region of airspace. Other practical limiting factors in terminal airspace capacity is the precautionary allowance for the potential outage of a radar sensor or other system component, as well as the allowance made for wake vortex avoidance.

Another area needing development is the accommodation of ADS-B technology in the presence of an established ground-based radar surveillance system. There are both technical and operational aspects to address, especially when one considers mixed equipage scenarios. Early on, for example, some aircraft will likely be equipped with *both* an SSR transponder and ADS-B. It has not been established how the ground system will integrate information from these two sources, nor has it been concluded how the resulting "hybrid" information will be displayed to the controller or fed to automation tools. Consideration must also be given to other mixed equipage scenarios in which some aircraft do not have ADS-B, as well as the less-likely situation of an aircraft having ADS-B, but no SSR capability.

This application examines the issues identified above with special emphasis on terminal area operations. First, the operational and technical performance of ADS-B will be established so as to explore ways that ADS-B can augment and improve overall terminal area radar operations. One focus will be on the inherent accuracy of ADS-B, and on the availability of aircraft-determined velocity vector information, as inputs to ground-based automation and controller tools. This will include use of ADS-B data to feed wake vortex modeling algorithms as a means to reduce separation. Another focus will investigate the availability and reliability of ADS-B for it to serve as a viable back-up to ground-based radar. In each case, the goal is to take advantage of ADS-B's strengths for the consideration of new separation minima, ground automation, and pilot/controller procedures.

This application will also examine the various mixed-equipage situations the terminal area controller and ground-based automation will likely face. This will include consideration of what information the controller needs to see on the display to effectively manage the situation. In addition, procedural simplicity for the pilot and controller will be pursued through the application basic human factors principles.

9.2: Radar Augmented with ADS-B in En Route Airspace

In the same way that ground-based radar data can sometimes be the limiting factor in the terminal environment, it can also be said of the en route environment. The accuracy of en route radar-derived aircraft position decreases with increasing range from the radar sensor. In addition, the update rate for en route radar is somewhat slower than for terminal radar, thereby introducing more difficulty in accurately establishing an aircraft track. For both the human controller and any supporting automation he/she may use, these uncertainties necessitate inclusion of separation margins. In cases where primary radar is the only positioning source, keeping targets sorted can be difficult for both the controller and ground system. In addition, the present system does not make any active use of information that could be provided by ADS-B, such as intent, bank angle, etc. As for the terminal area case described in the preceding application, the mixed equipage scenario is an area of concern.

The main objective of this application is to apply the features of ADS-B to technically and operationally supplement the existing en route surveillance system. Three aspects of this application are similar to the previous one (OA-9.1.1) for the terminal area. The first objective is to improve the accuracy of position information used by the controller and ground-based system. The second is to provide a back-up surveillance capability to enable consideration of reduced separation minima. The third is to ensure that the various mixed equipage situations are effectively addressed. A fourth objective, more unique to the en route environment, is the incorporation of longer-term intent information as supplied by some ADS-B-equipped aircraft.